Image Denoising Techniques Preserving Edges

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***Abstract*—The objective of this work is to propose an image denoising technique and compare it with image denoising using ridgelets. The proposed method uses slantlet transform instead of wavelets in ridgelet transform. Experimental result shows that the proposed method is more effective than ridgelets in noise removal. The proposed method is effective in compressing images while preserving edges.**

***Index Terms*—ridgelet, slantlet transform, image denoising, compression, huffman, edge**

I. Introduction

Image denoising is an important step in preprocessing of images. It is extremely difficult to form a global denoising scheme effective for different types of noisy images. Wavelets and ridgelets exploit redundancy in the image. Thresholding is applied to remove the noise without blurring edges. The important characteristic of the denoising technique introduced in this paper is that it can reduce noise without destroying edges in an image. So edge information is preserved and noise is well attenuated. The paper introduces a technique for image denoising that replaces wavelet transform in ridgelets by slantlet transform. The paper also focuses on image compression using the proposed method. Sparse representation of image data is achieved via invertible and non-redundant transforms [1], [2]. For practical applications, a discrete version of ridgelet transform is used. The building block of finite ridgelet transform (FRIT) is finite radon transform. Finite radon coefficients are optimally ordered [6] and one dimensional wavelet is applied on each slice of radon coefficients to give finite ridgelet transform [7]. Ridgelets give better edge representations than wavelets. To preserve more edges with reduced number of computations, slantlet transform is used instead of one dimensional wavelets in ridgelet transform [9], [10], [11]. In this paper, the compression of images is also carried out with the proposed method. Threshold is applied to the number of transform coefficients taken and huffman coding is done over it. At the decoder module, the original image is reconstructed. Similarly the image compression using ridgelets is carried out [4]. Both the reconstructed images are compared with the help of image quality metrics like PSNR, RMSE, Average Difference and Maximum Difference [7]. The proposed method is inspired on a wavelet based transform: ridgelet transform which is reviewed later. The rest of the paper is organized as follows. Section II and Section III briefs ridgelet transform and slantlet transform respectively. Section IV explains the proposed work. Section V and Section VI describes how the proposed work can be employed for image denoising and image compression. Numerical results are tabulated towards the end of the paper.

II. Ridgelet Transform

Given an integrable bivariate function f(x), its continuous ridgelet transform (CRT) in R^2 is defined as [4], [8]

$$CRT_f(a,b,\theta) = \int_{R^2} \psi_{a,b,\theta}(x) f(x) dx \qquad (1)$$

where the ridgelets $\psi_{a,b,\theta}(x)$ in 2D are defined from a wavelet-type function in 1-D $\psi(x)$ as

$$\psi_{a,b,\theta}(x) = a^{-1/2}\psi((x_1 \cos\theta + x_2 \sin\theta - b)/a). \qquad (2)$$

Ridgelets can be thought of as a way of concatenating 1D wavelets along lines. In 2D points and lines are related via radon transform which in turn links wavelets and ridgelets. In the FRAT domain, energy is best compacted if the mean is subtracted from the image f (i, j) [3]. To reduce the wrap around effect of FRAT, an optimal ordering of finite radon coefficients is done. To these optimally ordered radon coefficients, 1D wavelet transform is applied [8]. The ridgelets are used for compressing images where edge information is very critical. In denoising the images, ridgelets play an crucial role in preserving edges.

III. Slantlet Transform

The filterbank iteration structure of wavelet transform does not yield a discrete-time basis that is optimal with respect to time localization. Consider the equivalent structure of an iterated DWT filter bank. The slantlet filterbank is based on this structure. It will be occupied by different filters that are not products. With the extra degrees of freedom obtained by giving up the product form, it is possible to design filters of shorter length. The slantlet basis well suits piecewise linear signals, is orthogonal and it provides multiresolution decomposition. The filterbank is less frequency selective than traditional DWT filterbank due to shorter length of filters. The time localization is improved. Although both types of filterbanks, DWT and slantlet, possess same number of zero moments, the smoothness properties are different. The slantlet filter coefficients given by Selesnick [5] are

$$G_1(z) = \left(-\frac{\sqrt{10}}{20} - \frac{\sqrt{2}}{4}\right) + \left(\frac{3\sqrt{10}}{20} + \frac{\sqrt{2}}{4}\right)z^{-1} + \left(-\frac{3\sqrt{10}}{20} + \frac{\sqrt{2}}{4}\right)z^{-2} + \left(\frac{\sqrt{10}}{20} - \frac{\sqrt{2}}{4}\right)z^{-3} \qquad (3)$$

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$$\begin{aligned} F_2(z) = &\left(\frac{7\sqrt{5}}{80} - \frac{3\sqrt{55}}{80}\right) + \left(-\frac{\sqrt{5}}{80} - \frac{\sqrt{55}}{80}\right)z^{-1} \\ &+ \left(-\frac{9\sqrt{5}}{80} + \frac{\sqrt{55}}{80}\right)z^{-2} + \left(-\frac{17\sqrt{5}}{80} + \frac{3\sqrt{55}}{80}\right)z^{-3} \\ &+ \left(\frac{17\sqrt{5}}{80} + \frac{3\sqrt{55}}{80}\right)z^{-4} + \left(\frac{9\sqrt{5}}{80} + \frac{\sqrt{55}}{80}\right)z^{-5} \\ &+ \left(\frac{\sqrt{5}}{80} - \frac{\sqrt{55}}{80}\right)z^{-6} + \left(-\frac{7\sqrt{5}}{80} - \frac{3\sqrt{55}}{80}\right)z^{-7} \end{aligned} \tag{4}$$

$$\begin{aligned} H_2(z) = &\left(\frac{1}{16} + \frac{\sqrt{11}}{16}\right) + \left(\frac{3}{16} + \frac{\sqrt{11}}{16}\right)z^{-1} \\ &+ \left(\frac{5}{16} + \frac{\sqrt{11}}{16}\right)z^{-2} + \left(\frac{7}{16} + \frac{\sqrt{11}}{16}\right)z^{-3} \\ &+ \left(\frac{7}{16} - \frac{\sqrt{11}}{16}\right)z^{-4} + \left(\frac{5}{16} - \frac{\sqrt{11}}{16}\right)z^{-5} \\ &+ \left(\frac{3}{16} - \frac{\sqrt{11}}{16}\right)z^{-6} + \left(\frac{1}{16} - \frac{\sqrt{11}}{16}\right)z^{-7} \end{aligned} \tag{5}$$

The ability to model discontinuities is relevant in applications like edge detection. The support of the slantlet filters are less than those of the filters obtained by filterbank iteration. For scale i, there will be a reduction of 2^i-2 samples.

IV. Proposed Method

In ridgelets, the idea is to map a line singularity into a point singularity using radon transform and then wavelet transform can be used to effectively handle the point singularity in radon domain. In the proposed method, slantlet transform is performed on each row of radon coefficients. It is expected that the proposed transform will give high performance and strong properties. The proposed transform, combines together the good properties of local transforms. The properties of slantlet transform is higher than that of wavelet transform. In the FRIT domain, linear singularities are represented by a few large coefficients. Noisy singularities will be randomly located and significant coefficients are not generated. Hence thresholding, the FRIT coefficients can be very effective. The edges are critical in image analysis as they provide information on different regions in the image. By representing edges in a better way, the proposed method gives rich information in the spatial domain than wavelets. Image compression is carried out with the proposed method and the ridgelets. A comparative study is carried out with the help of different image quality metrics like RMSE (Root Mean Square Error), PSNR (Peak Signal to Noise Ratio), Average Difference and Maximum difference [7].

V. Image Denoising

Assume the original image be contaminated by an additive Gaussian white noise of variance σ^2 The denoising algorithm consists of following steps.

Step1: Apply proposed method to the noisy image.

Step2: Apply hard thresholding to the coefficients with universal threshold $T = \sigma\sqrt{2\log N}$ where N=p² pixels.

Step3: Inverse of the thresholded coefficients is taken. In order to overcome the "wrap around" effects and to enhance visual appearance of restored image wiener filtering is employed. The following figure illustrates denoising an image using FRIT and the proposed method.

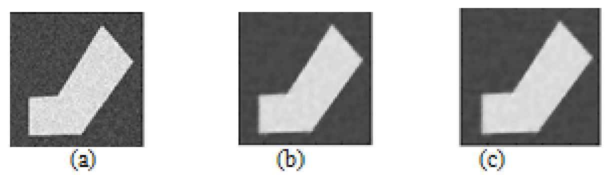

Figure 1. Illustration of denoising (a) noisy image (b) using FRIT (c) using proposed method

The Figure 1.(a) is a noisy image of SNR 32.49 dB, Figure 1.(b) employs FRIT for denoising (SNR=46.44dB) and denoised image using proposed method (46.50dB) is shown in Figure 1.(c) SNR value is high for Figure 1. (c)

VI. Experimental Results

Image compression using the proposed method and the ridgelet transform have been tested on many images. Here performance results for three images are given.

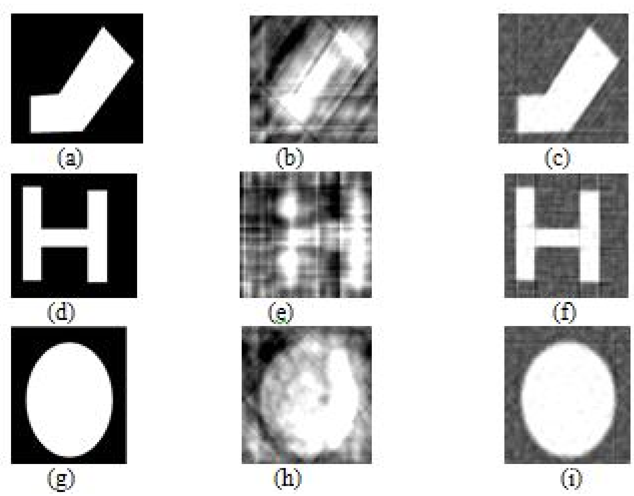

Figure 2. Compression of different images using the FRIT and proposed method.

The Figure 2. (a) to (c) show the original image (polygon.bmp), reconstructed image from proposed image compression and reconstructed image from image compression scheme using ridgelets respectively. Figure 2. (d) to (f) show original image (H shape.bmp), Figure 2. (g) to (i) show original image (circle.bmp) and their reconstructed images. The inferences obtained from the figures shown above are given in table I. The alphabets 'r' and 'p' denote ridgelet image compression and proposed image compression respectively.

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From the figures shown, a polygon, a H shape and a circle, it is evident that edges that are horizontal, vertical or having a slope are reconstructed better than curved edges. The proposed method gives better result than FRIT in the case of all the images shown above.

Conclusions

Denoising of an image with ridgelets and proposed method is carried out. The proposed method provides better noise removal. Compression of images using two different techniques is also discussed. The two image compression techniques are image compression using proposed method and ridgelet. The visual quality of images and the image quality metrics convey that the proposed technique gives better results.authors can conclude on the topic discussed and proposed. Future enhancement can also be briefed here.

TABLE I. Analysis using Image Quality Metrics

Image	PSNR	RMSE	AD	MD
Polygon(r)	80.7	0.02	0.29	1.35
Polygon(p)	93.14	0.005	0.059	0.72
H shape(r)	75.5	0.04	0.54	2.05
H shape(p)	93.13	0.005	0.064	0.53
Circle(r)	80.50	0.02	0.31	1.15
Circle(p)	91.84	0.006	0.06	0.60

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